

Airside Economizer – Comparing Different Control Strategies and Common Misconceptions

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ABSTRACT

Air-side economizer is broadly adopted in building HVAC design and operations. When the system is properly designed and the control sequence is properly implemented, air-side economizer provides significant energy savings. The design and operation basics of the air-side economizer are well understood and documented. However, some confusion and misconceptions do exist and are widely spread. When the economizer is not designed or implemented properly, an air handler cannot take full advantage of "free cooling", and, in some cases, could even cause significant energy waste.

This paper first introduces the fundamentals of the air-side economizer and typical control sequences. It goes on to discuss the determination of the activation temperature that enables or disables the dry-bulb temperature based economizer operation. The "best" activation temperatures that maximize the energy savings can be calculated based on weather data and are different from location to location. Activation temperatures for a few representative cities are presented. For drier weather regions, the activation temperatures are significantly higher than those for hot and humid weather regions.

The second part of the paper discusses the benefits of the enthalpy-enabled economizer and points out some important misconceptions that could significantly impact the energy savings of economizer operation. Specifically, it challenges the simplistic control strategy for the enthalpy-based economizer control that is commonly used in the industry.

Some questions this paper tries to answer include:

- 1. What is the optimal activation temperature for a temperature-based economizer that provides the most energy savings?*
- 2. How does enthalpy-based economizer compare with temperature-based economizer in energy savings?*
- 3. Does an economizer always save energy when the outside air enthalpy is below the return air enthalpy?*

4. Is it necessary for the outside air enthalpy to be lower than the return air enthalpy to enable the economizer and save energy?

5. What happens if the economizer control fails? What are the potential penalties?

Finally, an optimized economizer control strategy is proposed which is easy to implement and produces greater energy savings than both the temperature and conventional enthalpy based strategies.

INTRODUCTION

Air-side economizer, in short, is to introduce more outside air flow than required by ventilation needs, to supplement or eliminate mechanical cooling, when the outside air is cool enough to make it possible. Besides common components of a typical air-handling unit such as a cooling coil, a preheating coil and a supply fan (possibly with a Variable Frequency Drive, or VFD), a system with full economizer capability usually consists of a modulating return air damper as well as a modulating outside air damper. In larger systems, a modulating relief damper is also required to control building pressure.

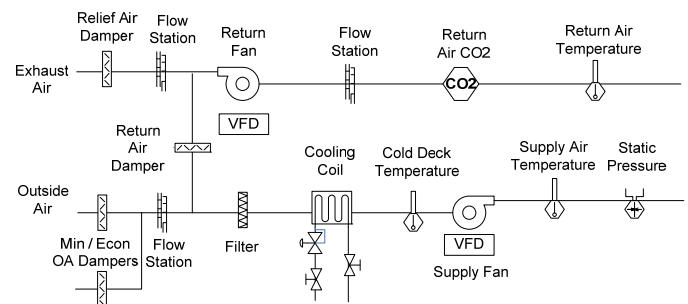


Figure 1. SDVAV unit with full economizer capability

Figure 1 shows the schematic of a typical air-handling unit (AHU) with full economizer capability. The unit has both a minimum outside air damper (typically open/close

control only) and an economizer outside air damper. The relief air damper and the return air damper are linked together so that as one opens, the other one closes. Under normal operation mode, the economizer damper is kept fully closed, the minimum outside air damper is open, the return damper is fully open, and the relief damper is fully closed. The supply fan speed is modulated to maintain the duct static pressure and the return fan speed may be controlled to track the supply air flow with some offset. Since the relief damper is closed, the difference between the supply and the return airflows equals to the amount of outside air flow.

When economizer operation is enabled, the economizer damper, together with the return air damper and the relief air damper are modulated in sequence with the cooling coil chilled water valve to control the discharge air temperature at its setpoint. Provisions have to be made to prevent all devices from fighting with each other. If the discharge temperature is higher than its setpoint, the economizer damper will open more to introduce more outside air (free cooling) to help reduce or eliminate mechanical cooling provided by the cooling coil. As the economizer damper fully opens, if the discharge air temperature is still higher than its setpoint, the return air damper will start to close to force even more outside air to enter the system. The chilled water valve should not start to open until the economizer damper has been fully opened and the return air damper fully closed (or closed to its control limit¹).

ECONOMIZER ACTIVATION STRATEGIES

The economizer control mode is typically enabled or disabled based on outside air dry-bulb temperature (temperature-based economizer) or outside air enthalpy in comparison with the return air enthalpy (enthalpy-based economizer). The most often-used activation strategy is simply based on the outside air dry-bulb temperature. This is because the key sensors required for the enthalpy-based economizer, i.e. the outside air relative humidity (RH) sensor and particularly the return air RH sensor, are often not available or unreliable. The maintenance and the accuracy of the RH sensors are also a major concern in implementing the enthalpy-based economizer.

For the temperature-based economizer, the activation temperature is the outside air temperature at which the economizer mode is activated. The determination of the activation temperature, however, is rather arbitrary. The ASHRAE handbook (2007) points out that the activation temperature may be significantly lower than the return air

temperature in humid climates where latent ventilation loads are significant. However, in dry climates, the activation temperature may be close to the return temperature. This is obvious when looking at Figure 2 and Figure 3, where Typical Meteorological Year (TMY) weather data for Houston (hot and humid) and Denver (cool and dry) are displayed on psychrometric charts. There is no surprise that the Denver weather is much cooler and drier than Houston. What is less obvious is that under the same outside air temperature, e.g., 65°F (18.3°C), the average outdoor air enthalpy in Denver (22.3 Btu/lb, or 51.9 kJ/kg) is considerably lower than that is in Houston (27.4 Btu/lb, or 63.7 kJ/kg). Therefore, running in the economizer mode when outside air is 65°F (18.3°C) (and under) seems to be an energy efficient move in Denver while it is probably not a good idea in Houston. In many real-world applications, the activation temperature is often set as low as 55°F (12.8°C) to be “safe”.

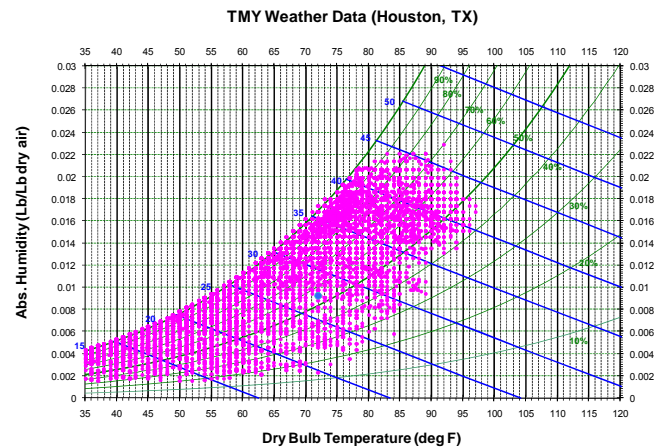


Figure 2. Houston weather data on Psychrometric chart

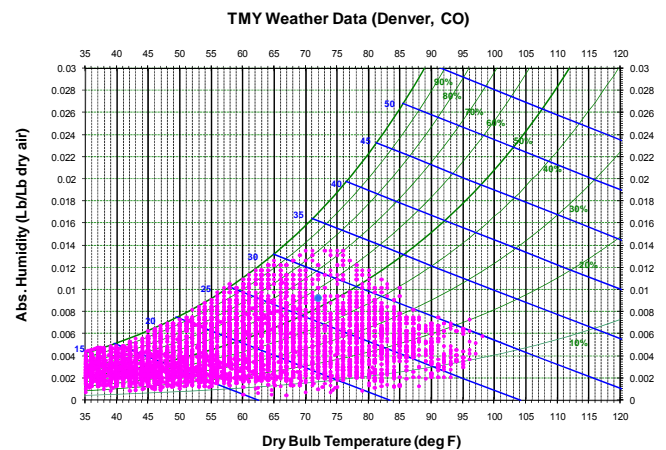


Figure 3. Denver weather data on Psychrometric chart

¹ It is possible that closing the return damper to certain limit will force the supply air fan to speed up if the outside air duct is relatively small compared to the return duct. Therefore it is necessary to enforce a control limit for the return air damper.

The economizer saves energy when it takes less energy (sensible and latent) to cool down the outside air to the discharge air temperature setpoint than the return air. Hour-by-hour energy consumption for economizer vs. non-economizer operations can be calculated and compared over a typical meteorological year for each location (city). Energy savings (defined as the difference between the mechanical cooling energy consumption for economizer and non-economizer operations) can be calculated and summed up for each 1°F outside air temperature bin², as shown in Figure 4 for Phoenix, Arizona.

As shown in Figure 4, the economizer energy savings are positive when the outside air temperature is below 70°F and become negative (energy penalty) as the temperature gets higher. Therefore for Phoenix, Arizona, the economizer energy savings are maximized if economizer is activated whenever outside air temperature is below 70°F (21.1°C).

Figure 5 shows the accumulated savings (or penalties) of economizer operation for all hours with outside air temperature less than or equal to a certain temperature. For example, the figure shows that the accumulated savings is 16,970 Btu/lb (39472 kJ/kg) in Denver if economizer is enabled whenever OAT is below 60°F (15.6°C), while this savings is only 7,060 Btu/lb (16422 kJ/kg) in Houston and even less in Miami. As the OAT continues to move higher, the economizer savings continues to grow but then the savings start to peak (at different OAT for different cities) and then start to drop. For each curve, the peak represents the maximum savings that can be achieved with temperature-based economizer where the temperature corresponding to the peak is the optimal activation point.

Among the six US cities analyzed, Denver shows the greatest savings potential for economizer while potential savings for Miami is negligible. The optimal activation temperatures vary from 62°F (16.7°C) for Houston to 70°F (21.1°C) for Phoenix. The maximum savings and the optimal activation temperatures for the six cities are shown in Table 1. Another important fact illustrated in Figure 5 is the potential damage an economizer control sequence can cause if economizer is inadvertently activated for higher temperature conditions. “Persistent Savings” shown in Table 1 is the savings (or waste if negative) that can be achieved if economizer is enabled all year round. Persistence ratio (or “P-ratio” as shown in the table) is defined as the ratio of the persistent savings over the maximum savings, and can be used as a gauge for potential penalty for running the economizer all year round. The penalties range from

“minor” for Denver to “devastating” for Houston and Miami.

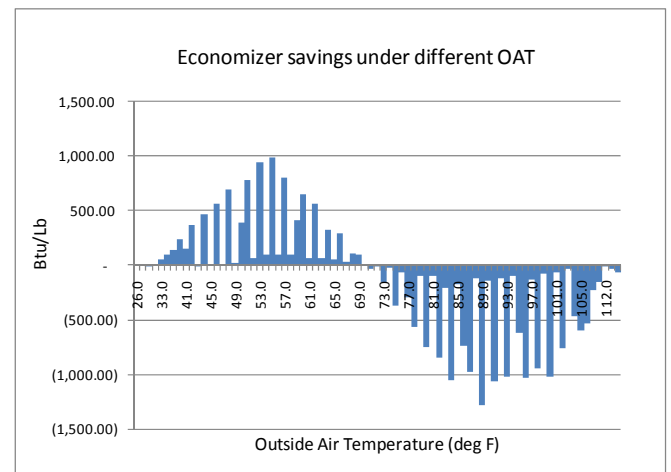


Figure 4. Savings (or penalty) from economizer operation under different OAT (Phoenix, AZ)

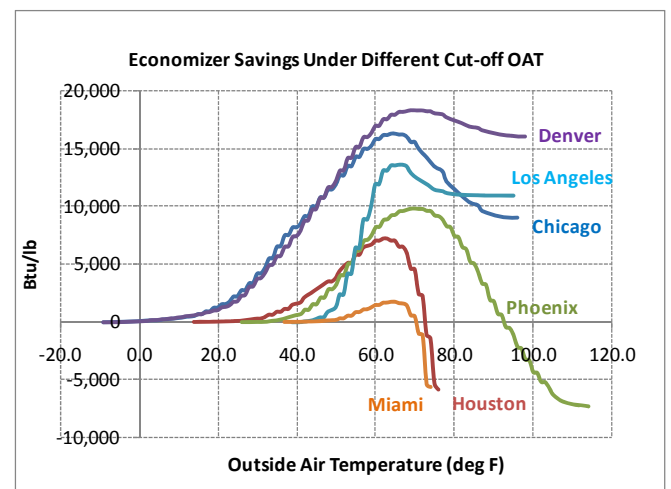


Figure 5. Economizer savings signature chart (below zero represents energy penalty)

Table 1. Economizer activation temperatures and max potential savings and penalties for different cities

City Name	Switchover OAT deg F (deg C)	Max Savings Btu/Lb (KJ/Kg)	Persistent Savings Btu/Lb (KJ/Kg)	P-Ratio
Chicago, IL	64 (17.8)	16,278 (37863)	9,033 (21010)	55%
Houston, TX	62 (16.7)	7,243 (16847)	-30,898 (-71868)	-427%
Phoenix, AZ	70 (21.1)	9,814 (22828)	-7271 (-16911)	-74%
Denver, CO	69 (20.6)	18,333 (42642)	16,063 (37362)	88%
Los Angeles, CA	64 (17.8)	13,491 (31381)	10,898 (25348)	81%
Miami, FL	65 (18.3)	1,765 (4104)	-52,016 (-120990)	-2948%

² The return air temperature of 72°F (22.2°C) and relative humidity of 55% are assumed in savings calculation.

Another often-used activation mechanism is based on the enthalpy comparison between the outside air and the return air. The economizer mode is enabled when the outside air enthalpy is lower than that of the return air. This mechanism usually provides a broader operation range for the economizer than the temperature-based economizer, especially when a conservative activation temperature is used for the latter. For example, for Houston, Texas, an enthalpy-based economizer triggers economizer mode for 3,041 hours (assuming the return air is maintained at 72°F (22.2°C) and 55% relative humidity), while the temperature-based economizer (with activation temperature of 62°F, or 16.7°C) enables “economizer” mode for 2,780 hours. Figure 6 shows the weather data that qualifies the enthalpy-based economizer but not the temperature-based economizer. In comparison to the temperature-based economizer, the enthalpy-based economizer increases the economizer operating hours by 9.4%. However, the savings from the enthalpy-based economizer is only 3.7% more than the temperature-based economizer. In fact, enabling the economizer by mere comparison between outside air and return air enthalpies is a flawed control strategy and it can be wasteful under certain weather conditions, as explained in the section below.

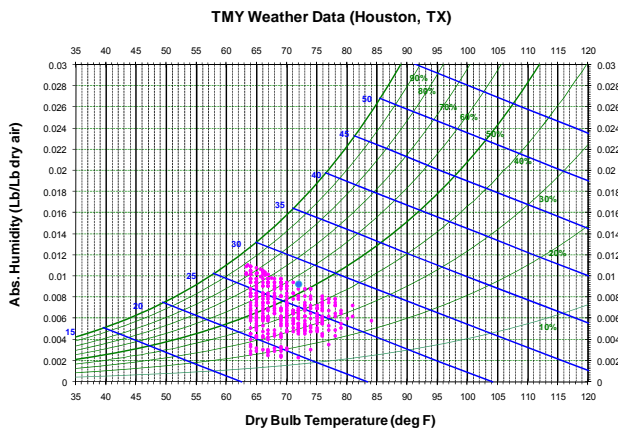


Figure 6. Weather data points that enable enthalpy-based economizer but not temperature-based economizer

COMMON MISCONCEPTIONS

One of the most common misconceptions is that the economizer operation always saves cooling energy when the outside air enthalpy is lower than the return air enthalpy. Most of the enthalpy-based economizer applications implement a control strategy by simply comparing the outside air enthalpy against the return air enthalpy.

Assume that the outside air temperature is 82.6°F (28.1°C) with relative humidity of 20% (point “O” in Figure 7) and that the return air temperature is 72°F (22.2°C) with relative humidity of 55% (point “R”). Since the enthalpy of the outside air (25.8 Btu/lb, or 60.0 kJ/kg) is slightly lower than the return air (27.4 Btu/lb, or 63.7 kJ/kg) the economizer mode is enabled. Suppose the discharge air temperature setpoint is 55°F (12.8°C), the control sequence will introduce 100% outside air into the AHU since the discharge air temperature setpoint cannot be maintained. The chilled water valve on the cooling coil will open and cool the outside air from 82.6°F (28.1°C) to 55°F (12.8°C) (point “D”), consuming 7.6 Btu/lb (17.7 kJ/kg) in mechanical cooling. In comparison, if economizer is disabled and 100% return air is circulated through the AHU, the return air is cooled down from 72°F (22.2°C) to 55°F (12.8°C) (point “C”), consuming 4.2 Btu/lb (9.8 kJ/kg) in mechanical cooling. It is obvious the economizer is undesirable in this case. In fact, any time when the outside air temperature is higher than the return air temperature, it is not economical to use the economizer mode.

It is worth mentioning that the conditions presented in Figure 7 are not likely to be sustainable once the economizer is enabled. With 100% outside air (warm and dry) introduced into the unit and circulated through the conditioned space, the relative humidity in the space shall start to drop gradually, bringing return air enthalpy down to a level that is closer to (or even lower than) the outside air enthalpy, eventually disabling the economizer mode. However, as a control strategy that is to be implemented in a real-time building automation system (BAS), the mere comparison between the outside and return air enthalpies is obviously flawed and should be corrected.

Another misconception is that the outside air enthalpy has to be lower than the return air enthalpy for economizer to save cooling energy. This is also not true. For example, as shown in Figure 8, the return air is 72°F (22.2°C) at 28%RH (point “R”) and the outside air is 65°F (18.3°C) at 70% (point “O”). The outside air enthalpy (25.6 Btu/lb or 59.5 kJ/kg) is higher than the return air (22.3 Btu/lb, or 51.9 kJ/kg). However, cooling the outside air to 55°F (12.8°C) (point “C”) uses less mechanical cooling energy (2.4 Btu/lb, or 5.6 kJ/kg) than cooling the return air to the same discharge temperature of 55°F (12.8°C) (point “D”), which takes 4.1 Btu/lb (9.5 kJ/kg). So in this case, even though the outside air enthalpy is higher than the return air enthalpy, it is more energy efficient to enable the economizer. Again, the conditions presented in Figure 8 are usually not sustainable once the economizer mode is enabled.

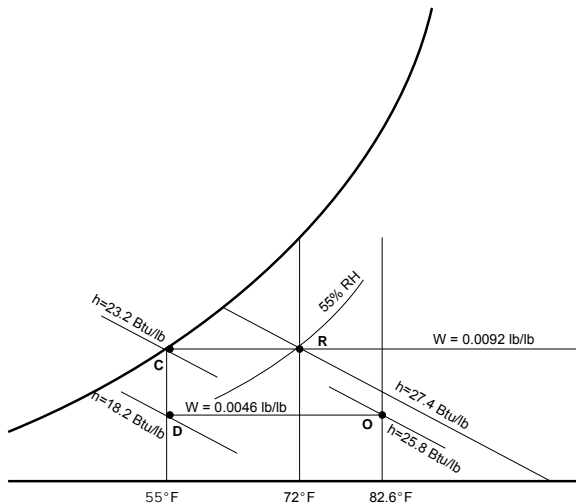


Figure 7. Economizer misconception illustrated (1)

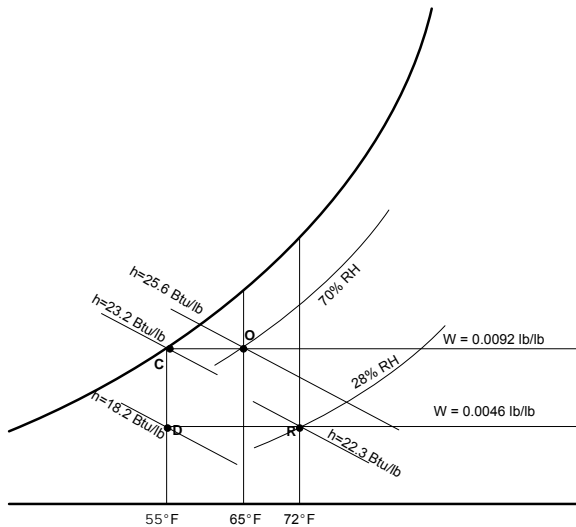


Figure 8. Economizer misconception illustrated (2)

AN OPTIMIZED ENTHALPY-BASED ECONOMIZER ACTIVATION STRATEGY

An optimized enthalpy-based economizer activation strategy has been developed which enables the economizer when the following two conditions are both satisfied: 1) the outside air enthalpy is less than 27.4 Btu/lb (63.7 kJ/kg), which corresponds to a typical comfort space condition of 72°F (22.2°C) and 55%RH, and 2) the outside air temperature is lower than the return air temperature. This activation strategy does not rely on the return air relative humidity and achieves better energy savings than both the temperature-based economizer and the enthalpy-based economizer discussed in previous sections.

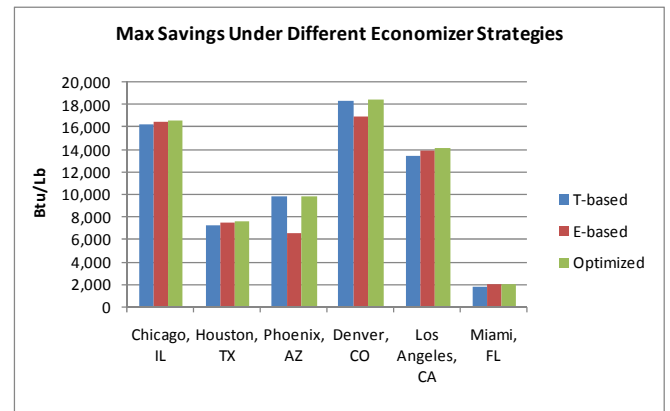


Figure 9. Comparison of maximum savings under different economizer strategies

Energy savings that can be achieved under all three economizer activation strategies are calculated and are shown in Figure 9, where “T-based”, “E-based” and “Optimized” represents the temperature-based, enthalpy-based and the optimized enthalpy-based control strategies respectively. It is very interesting to notice that for Phoenix and Denver (notably the “dry” weather cities), the conventional enthalpy-based economizer saves noticeably less energy than the temperature-based strategy, due to reasons that have been explained previously. The temperature-based activation strategy, once the optimal activation temperature is determined for a particular city, achieves nearly as much savings as the optimized enthalpy-based economizer, which overall ranks the best strategy of the three.

CONCLUSIONS

Three economizer activation strategies are investigated in the paper. The temperature-based activation strategy works well as long as the optimal activation temperature is identified, which varies significantly from city to city. If the economizer is activated at a temperature away from the optimal temperature, either lower or higher, the savings deteriorate quickly. The conventional enthalpy-based economizer strategy is flawed and the savings can be reduced for some locations. The optimized enthalpy-based economizer is easy to implement and achieves the maximum energy savings.

REFERENCES

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